FROM DESIGN TO MARKET

ELECTROMAGNETIC COMPATIBILITY (EMC) ENGINEERING

4T SEMINAR

APRIL 13, 2016

HILTON HOTEL / ANKARA

Levent Sevgi

Okan University
Department of Electrical and Electronics Engineering
Akfırat – Tuzla / Istanbul, 34959, Turkey
levent.sevgi@okan.edu.tr

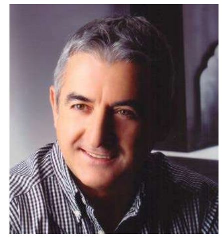
Copyright

Abstract

This presentation explores the fundamentals of EMC engineering, examines fundamental terms, concepts and definitions, highlights issues and the procedures from design to market for both technical and non-technical people, including market control, accreditation, calibration, EMC tests and measurements, and EMC protection.

Index Terms: EMC, market control, accreditation, calibration, EMC tests and measurements, EMC protection.

Biography



Born in Akhisar / Turkey on 1st January 1958.
He received his BsEE, MsEE and PhD degrees in Electronic Engineering from Istanbul Technical University (ITU) in 1982, 1984 and 1990, respectively. In 1987, while working on his PhD, he was awarded a fellowship that allowed him to work with Prof. L. B. Felsen at Weber Research Institute / New York Polytechnic University York for two years. His work at the Polytechnic concerned the propagation phenomena in non-homogeneous open and closed waveguides.

He was with Istanbul Technical University (1991–1998), TUBITAK-MRC, Information Technologies Research Institute (1999–2000), Weber Research Institute/ Polytechnic University in New York / USA (1988–1990), Scientific Research Group of Raytheon Systems, Canada (1998 – 1999), Center for Defense Studies, ITUV-SAM (1993 –1998 and 2000–2002) and with University of Massachusetts, Lowell (UML) MA/USA as a full-time faculty (2012 – 2013) and with Doğuş University (2001-2014). Since Sep 2014, he has been with Okan University.

He has been involved with complex electromagnetic problems and complex communication and radar systems for nearly three decades. His research study has focused on propagation in complex environments, analytical and numerical methods in electromagnetic, EMC/EMI modeling and measurement, communication, radar and integrated surveillance systems, surface wave HF radars, FDTD, TLM, FEM, SSPE, and MoM techniques and their applications, RCS modeling, bio-electromagnetics. He is also interested in novel approaches in engineering education, teaching electromagnetics via virtual tools. He also teaches popular science lectures such as Science, Technology and Society.

He is a Fellow member of the IEEE, an AdCom member of the IEEE Antennas and Propagation Society (2013-2015), the writer/editor of the "Testing ourselves" Column in the IEEE Antennas and Propagation Magazine (since Feb 2007) and a member of the IEEE Antennas and Propagation Society Education Committee (since Jun 2006). He is also a member of several editorial boards (EB), such as the IEEE Antennas and Propagation Magazine (since 2007), the IEEE Access (2017-2019), Wiley's International Journal of RFMiCAE (since 2002), etc.

He has published many books/book chapters in English and Turkish, over 170 journal/magazine papers/tutorials and attended nearly 100 international conferences/symposiums.

His two books "Complex Electromagnetic Problems and Numerical Simulation Approaches" and "Electromagnetic Modeling and Simulation" were published by the IEEE Press - Wiley in 2003 and 2014, respectively. His third book, "A Practical Guide to EMC Engineering" was published by ARTECH House (Norwood/MA, USA and London, UK) in March 2017. His fourth book "Guided Wave Propagation and Parabolic Equation Modeling" with Gökhan Apaydın will be published by the IEEE Press - Wiley around Oct 2017.

Outline

- EU EMC Directive and CE Marking
- World Trade and Accreditation
- EMC Tests and Measurements
- EMC Problems' Natures and EMC Philosophy
- EM and TL Theories
- Basic EMC Problems
- EMC and Protection
- Conclusions

Definition

➔ DEVICE - DEVICE INTERACTION

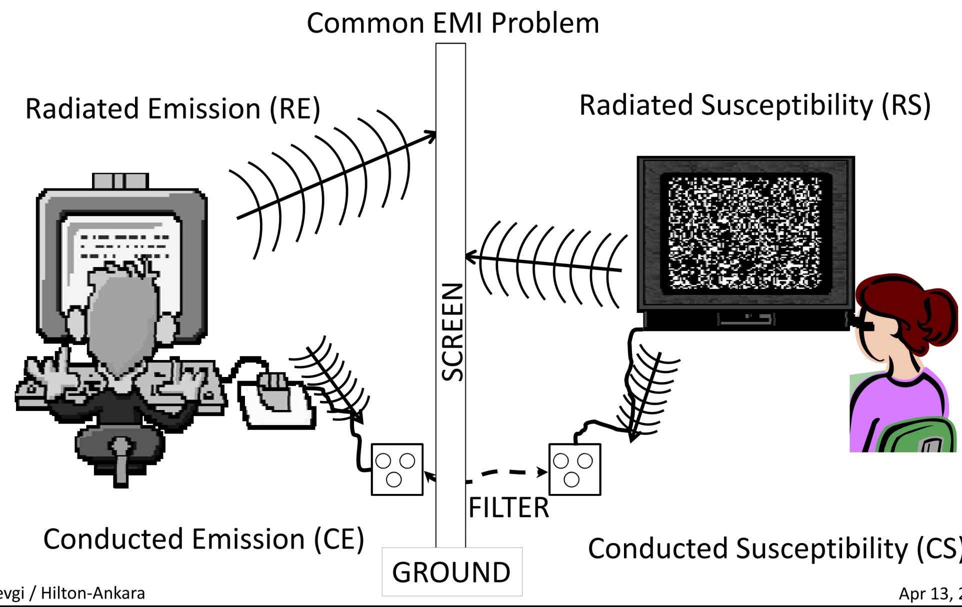
EMC ENGINEERING

➔ DEVICE - HUMAN (TISSUE) INTERACTION

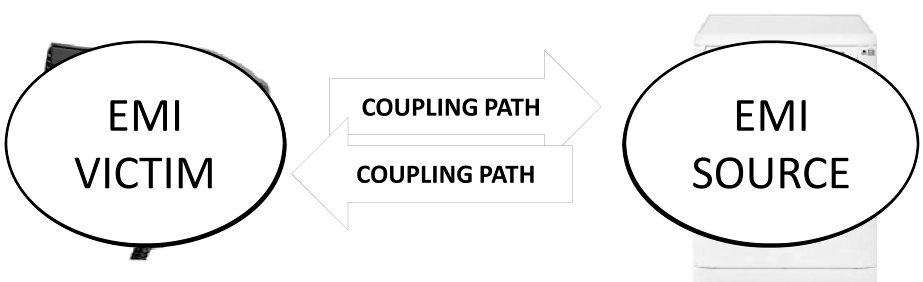
BEM ENGINEERING

L. Sevgi / Hilton-Ankara
Apr 13, 2016

Typical EMC/EMI Environment



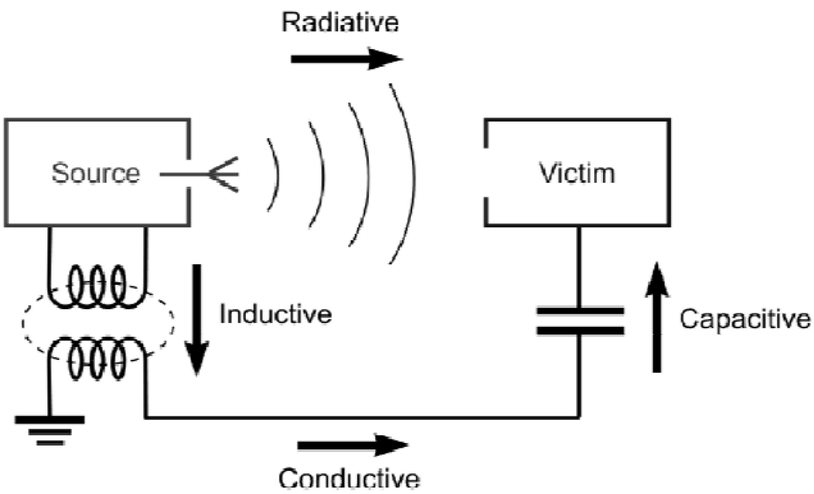
EMC Problem Definition



<u>Solution?</u>

- Reduce EMI at the Source
- Strengthen the Victim
- Remove the coupling Path

EMC and Coupling



EU Directives

- EMC DIRECTIVE (89/336/EEC) -> EMC DIRECTIVE (2004/108/EC)

The EMC Directive applies to all electronic or electrical products liable to cause or be disturbed by an electromagnetic disturbance. As a result a large number of manufacturers in the electronics or electrical industries need to ensure that their products are compliant with the requirements of the Directive and be able to demonstrate that this is the case in order to affix a valid CE Marking to them.

L 390/24 EN Official Journal of the European Union 31.12.2004

DIRECTIVE 2004/108/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 15 December 2004

on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC

(Text with EEA relevance)

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty establishing the European Community, and in particular Article 95 thereof,

(3) The electromagnetic compatibility of equipment should be regulated with a view to ensuring the functioning of the internal market, that is to say, of an area without internal frontiers in which the free movement of goods, persons, services and capital is assured.

CE Marking

- The **CE marking** (also known as **CE mark**) is a mandatory conformance mark on many products placed on the single market in the European Union (EU) & European Economic Area (EEA).
- The **CE marking** certifies that a product has met EU consumer safety, health or environmental requirements. Originally "CE" stood for "Communauté Européenne" ("European Community") or "Conformité Européenne" ("European Conformity").
- According to the European Commission today, the CE logo has become a symbol for free marketability of industrial goods within the EEA without any literal meaning.
- By affixing the CE marking to a product, the manufacturer – on his sole responsibility – declares that it meets EU safety and health and environmental requirements.

CE Marking

The procedure

- Identify applicable "Directives".
- Identify applicable "Conformity Assessment Module".
- Identify applicable "Standard".
- Test a sample of the product, either by yourself or in a lab.
- Compile "Technical Documentation".
- Sign the "Declaration of Conformity (DOC)".
- Affix "CE Mark" on the product
- You're free to go to Market.

EMC Standards

- *Basic Standards:* Define and describe the EMC problem, measurement and test methods, principle measuring equipment and test set up. They contain no limits and state no interference criteria. Basic immunity and emission EMC standards are specified by the IEC and CISPR, respectively, (for example, CISPR 16 and IEC 61 000).
- *Generic Standards:* are standards that have to do with a particular EM environment. They specify appropriate series of requirements and tests which are used for all products and systems in this environment. There are two major environments: (1) Residental, commercial and light industry, (2) Industry.
- *Product Family Standards:* contain special limits for emission and immunity for a specific category of devices (e.g., CISPR 22, Information Technologies). They contain many basic standards.
- *Product Specific Standards:* are for specific product (e.g., prEN50220 is immunity standards for hearing aid products).

EMC Standards

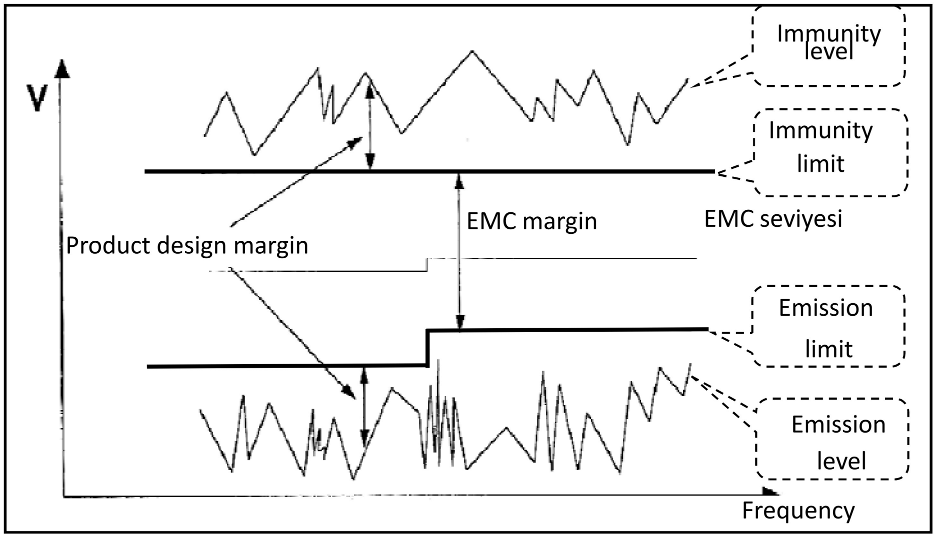
EMC Directive Standards

Harmonized standards for the implementation of the Council Directive 89/336/EEC (2000/C 359/02).

CENELEC

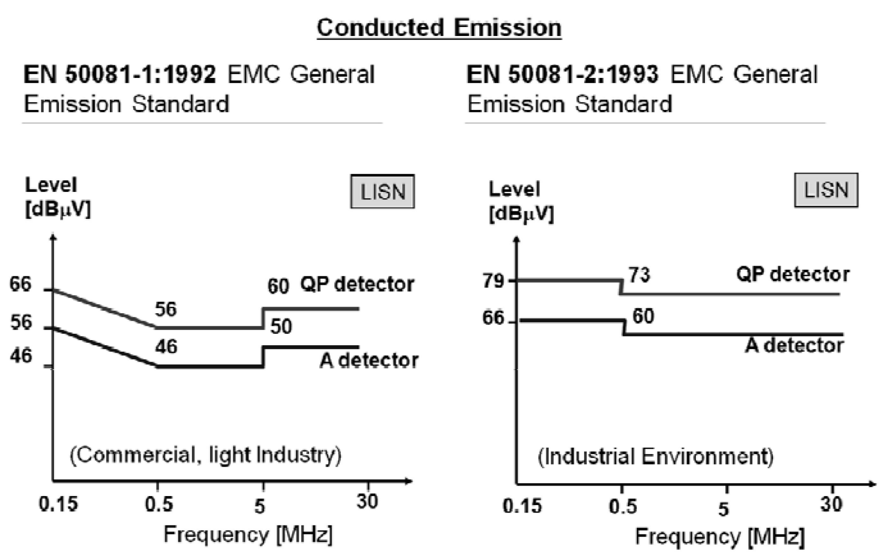
- **EN 50081-1:1992**—Electromagnetic compatibility—Generic emission standard—Part 1: Residential, commercial, and light industry.
- **EN 50081-2:1994**—Electromagnetic compatibility—Generic emission standard—Part 2: Industrial environment.
- **EN 50082-1:1998**—Electromagnetic compatibility—Generic immunity standard—Part 1: Residential, commercial, and light industry.
- **EN 50082-2:1995**—Electromagnetic compatibility—Generic immunity standard—Part 2: Industrial environment.
- **EN 50083-2:2001**—Cabled networks for television signals, sound signals, and interactive services—Part 2: Electromagnetic compatibility for equipment; Amendment A1:1997 to EN 50083-2:1995.

EMC/EMI Limits



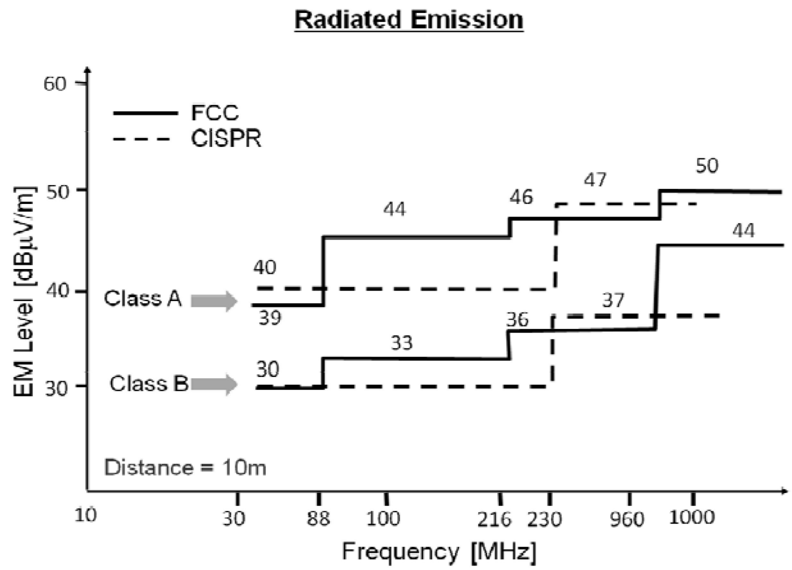
L. Sevgi / Hilton-Ankara
Apr 13, 2016

EMC Limits



L. Sevgi / Hilton-Ankara
Apr 13, 2016

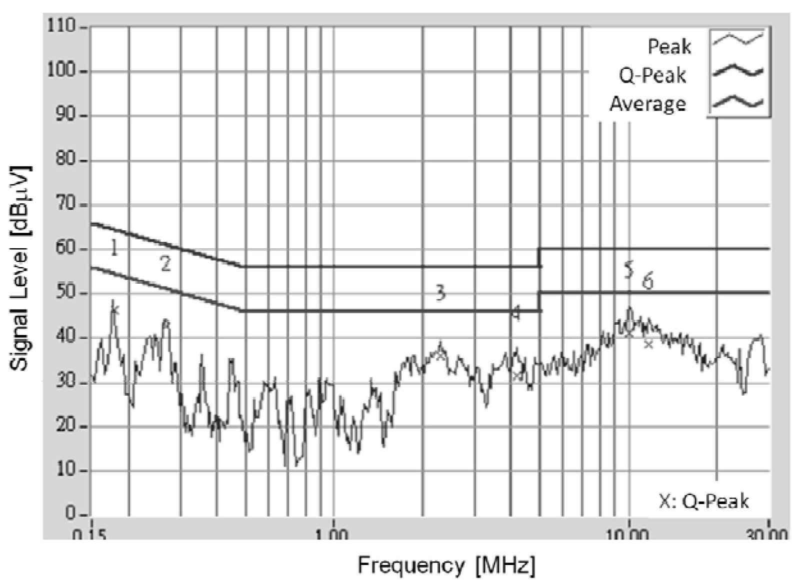
EMC Limits



L. Sevgi / Hilton-Ankara

Apr 13, 2016

EMC Tests & Measurements



L. Sevgi / Hilton-Ankara

Apr 13, 2016

Results & Consequences

- EU rapid alert system RAPEX informs Member States and EC on measures taken to prevent or restrict the marketing or use of products posing a serious risk to the health and safety of consumers with the exception of food, pharmaceutical and medical devices, which are covered by other mechanisms.
- Every Friday, the EC publishes a weekly overview of the products posing a serious risk which gives information on the product, the identified risk and measures that were taken in the notifying country.
- In Turkey, **Ministry of Science, Industry and Techn**ology is responsible for Random Surveillance and Control. Equipment fail to meet requirements during these controls are banned from the Market.
- A **product recall** (a request to return a product after the discovery of safety issues or product defects that might endanger the consumer or put the maker/seller at risk of legal action) is also another consequence.

Results & Consequences

1. Piyasaya arzının yasaklanm
2. Piyasada bulunan ürünlerin
3. Güvenli hale getirilmesi m güvenli hale getirilmesi,
4. Güvenli hale getirildiği kar
5. Güvenli hale getirilemeyen

YAPTIRIMIN HUKUKİ DA
Hazırlanması ve Uygulamasına D

YAPTIRIMA KARŞI İTİRAZ
Yargılama Usulü 7. Maddesine gö
en geç atmış (60) gün içinde, yetk
yapılmamış olması halinde idari y

yukarıda tarih-sayısı verilen onay

YAPTIRIMIN TÜRÜ VE İÇER

Sanayi Bakanlığı'ndan 18 ürün hakkında toplatma kararı

Sanayi Bakanlığı, güvensizliği tespit edilen 18 ürüne ilişkin toplatma kararı aldı.
23 Haziran 2015 Salı

Bakanlık DİKKAT!!! Bu ürünler toplanıyor

"Bakanlık tarafından 4703 sayılı Ürünlere İlişkin Teknik Mevzuatın Hazırlanması ve Uygulanmasına Dair Kanunun 11'inci maddesi kapsamında, güvensizliği tespit edilen ve hakkında piyasaya arz yasağı, toplatma ve bertaraf kararı verilerek mevzuat ile belirlenen süreçleri tamamlanan yaptırım kararlarına ilişkin bilgilere, Bilim, Sanayi ve Teknoloji Bakanlığı Piyasa Gözetimi ve Denetimi Yönetmeliğinin 10'uncu maddesine göre aşağıda yer verilmiştir.

Sanayi Bakanlığı tarafından 4703 sayılı Ürünlere İlişkin Teknik Mevzuatın Hazırlanması ve Uygulanmasına Dair Kanunun 11'inci maddesi kapsamında, güvensizliği tespit edilen ve hakkında piyasaya arz yasağı, toplatma ve bertaraf kararı verilerek mevzuat ile belirlenen süreçleri tamamlanan yaptırım kararlarına ilişkin bilgilere, Bilim, Sanayi ve Teknoloji Bakanlığı Piyasa Gözetimi ve Denetimi Yönetmeliğinin 10'uncu maddesine göre aşağıda yer verilmiştir

Bakanlığımızca, 4703 sayılı Kanun kapsamında güvensizlik nedeni ile alınan toplatma kararlarının mevzuat ile belirlenen süreçlerinin tamamlanmasını müteakip duyurulmasına devam edilecektir. Toplatmaya konu ürünlerden ellerinde bulunanların, ürünün üreticisine başvurması gerekmektedir.

Bu ilan, üreticilerin aşağıda yer verilen marka/model ürünlerine yönelik olup, üreticilerin tüm ürünlerini kapsamamaktadır.

ÜRETİCİNİN UNVANI	MARKA/MODEL
Simeks Elektronik Malzeme Şti	Adline Marka OLS02/21 Model Ağır Yük Sistemi.
İnceay Sobaları	İnceay Marka LPG'li Mangal
[illegible] A.Ş.	Uğur Marka LPG'li Mangal
Fatih Elektrik Ltd. Şti.	Fatih Marka Kablosuz 4'lü Grup Priz
Işık Kaynak Makina San. ve Tic. Ltd. Şti.	Işık Marka INV DC 180A Model Kaynak Makinası
Urcan Bobinaj Atölyesi Nuray Urcan	URC Markalı M/00 Model Elektrik Motorlu Su Pompası
Star Pompa San. ve Tic. Ltd. Şti.	DEEPS Markalı SPD50 Model Elektrik Motorlu Dalgıç Pompası
Simteks Tekstil Ltd. Şti	Simkor Marka Lav Taşlı LPG'li Mangal
Yıldız Madeni Eşya Ltd. Şti.	Yıldız Marka LPG'li Kalorifer Sobası
Samsun Hırdavat Abdülhamit Fişenoğlu	Ky - PAX Markalı AW - BC520T Model Motorlu Tırpan
Samsun Hırdavat Abdulhamit Fişenoğlu	Ky - PAX Markalı AW - BC521 Model Motorlu Tırpan
DPS Pompa Sistemleri San. ve Tic. Ltd. Şti	DPS Marka KSM2 75F Model Dalgıç Pompası
Özen Makina Sanayi ve Ticaret A.Ş.	ÖZEN Marka DC 180 Model Ark Kaynak Makinası
Zeyhan Elektrik Ltd. Şti.	Gold Marka DG Y003 Model 3W Ledli Armatür
Motif Hırdavat Sanayi Ltd. Şti.	BUL MAX Marka BMX 245 Model Taşınabilir Daldırma Tipi Su Isıtıcısı
Uğur Aydınlatma San. ve Tic. Ltd. Şti.	CATA Markalı CT-2202 Model Balast
Uğur Kalorifer Sanayi- Kemal ÇOŞKUN	US-EF Marka UKS-4GO-4011 Model 4 Gözlü, Doğal Gazla Çalışan Ev Tipi Set Üstü Ocak
Kaplanlı Endüstriyel Mutfak Ekipmanları Ltd. Şti.	Kaplanlı Marka 2 Demlikli (40'lık) LPG'li Çay Ocağı

EMC Tests & Measurements

- EMC tests and measurements must be

  reliable

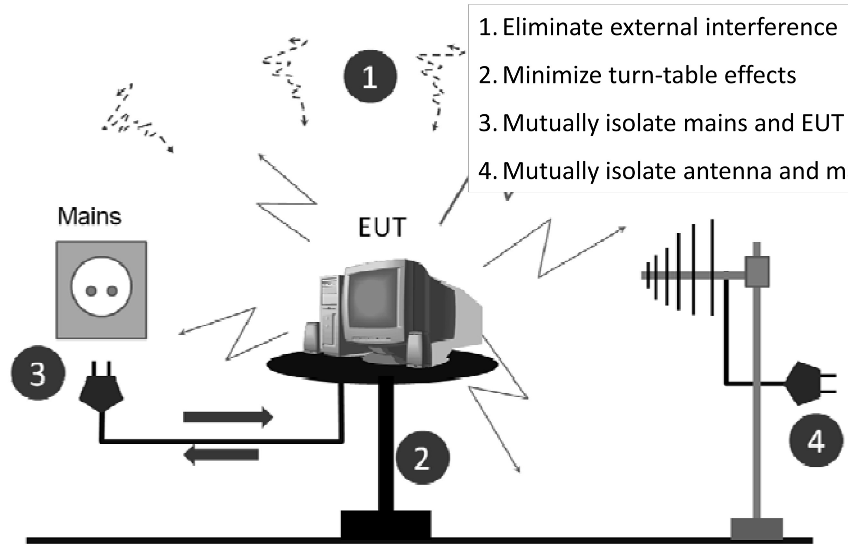
  realizable

  repeatable.

  These three factors are fundamentals of **traceability**.
- Traceability is the ability / possibility of a test or measurement result/value available for a comparison within a chain of national/international references within a specified uncertainty.

EMC Tests & Measurements

1. Eliminate external interference
2. Minimize turn-table effects
3. Mutually isolate mains and EUT
4. Mutually isolate antenna and mains



EMC Tests & Measurements

1. The measurements can be conducted in an anechoic chamber or in an open field test area (OFTA). In either case, one needs to be sure that all undesired environmental interference and noise source are well-isolated. This is achieved by OFTA / anechoic chamber calibration.
2. The Equipment under Test (EUT) is located on a turn-table with negligible EM scattering characteristics. Standards list all critical information related to that.
3. EUT is connected to the mains and worst case emissions are recorded by a broad band receive antenna. This needs to find out EUT's maximum emission direction, orientation, etc. The staff must show that there is no mutual disturbance between the mains and EUT and they are well-isolated.
4. Emissions captured by the receive antenna are recorded by an EMI receiver. The antenna, cables, and the EMI receiver must all be calibrated.

Monitoring / Provision / Authorization

- Who will do the tests & measurements?
- In which environments will the tests & measurements be performed?
- What type of equipment will be used during the tests & measurements?
- Who will monitor / control the tests & measurements?
- Who will control & authorize everything / process?
- How will us be sure that everything is OK during these processes?
- **THE ANSWER COMES WITH ACCREDIATION!**

Accreditation

The act of official granting credit or recognition by an authority. The difference from certification is that it includes quality management system.

TARGET

One Standard

One Test / Measurement

One Certificate

GET a RECOGNITION worlwide!

L. Sevgi / Hilton-Ankara Apr 13, 2016

Accreditation

Accreditation of Scope/Activity:	**Standard**
Laboratories Testing and Medical examinations	ISO/IEC 17025 ISO 15189
Laboratories Calibration	ISO/IEC 17025
Certification Bodies Product certification	EN 45011 and ISO/IEC 17065
Certification Bodies Certification of persons	ISO/IEC 17024
Certification Bodies Management systems certification	ISO/IEC 17021
Inspection	ISO/IEC 17020
Verification	EN/ISO 14065

L. Sevgi / Hilton-Ankara Apr 13, 2016

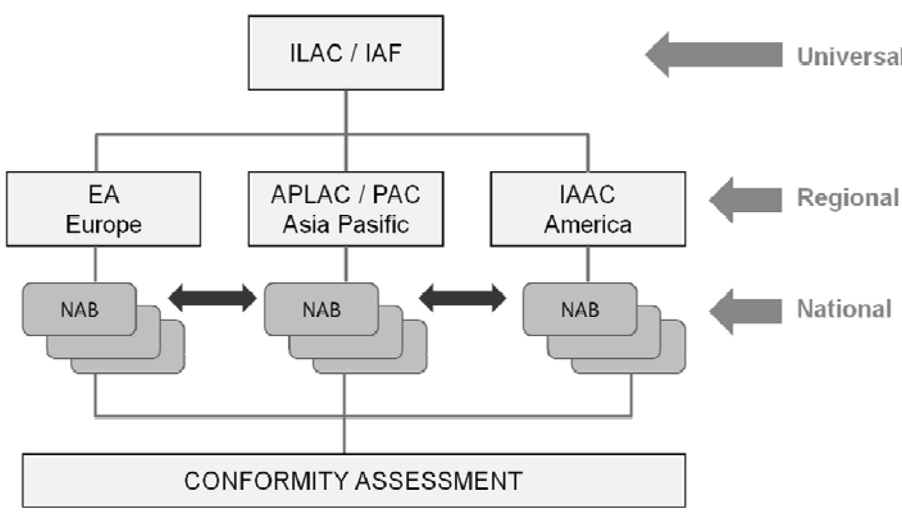
Accreditation

Market Control

- Worldwide accreditation bodies are International Accreditation Forum (IAF), International Laboratory Accreditation Cooperation (ILAC), European Cooperation for Accreditation (EA), Inter-American Accreditation Cooperation (IAAC), and Asia Pacific Laboratory Accreditation Cooperation, (APLAC).
- A global acceptance of the services provided with these bodies is established by signing multi-literal agreements (MLA) which constructs the essential trusting mechanism.
- The MLA signatories recognize and accept the **equivalence** and the **reliability** of the accreditation systems operated by the signing members.

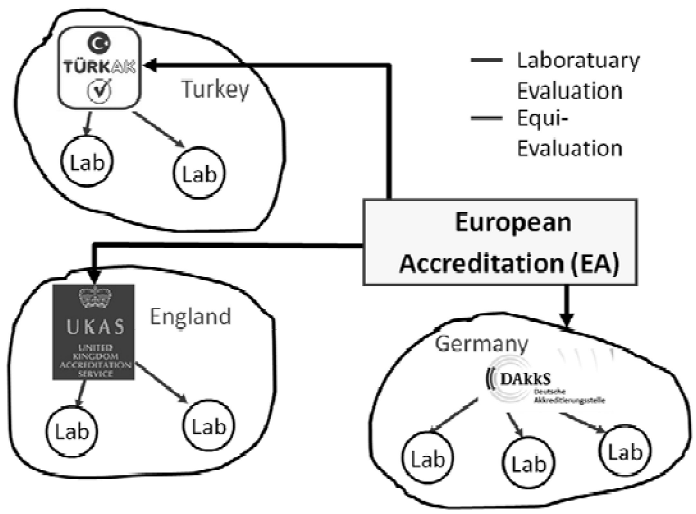
L. Sevgi / Hilton-Ankara Apr 13, 2016

Accreditation



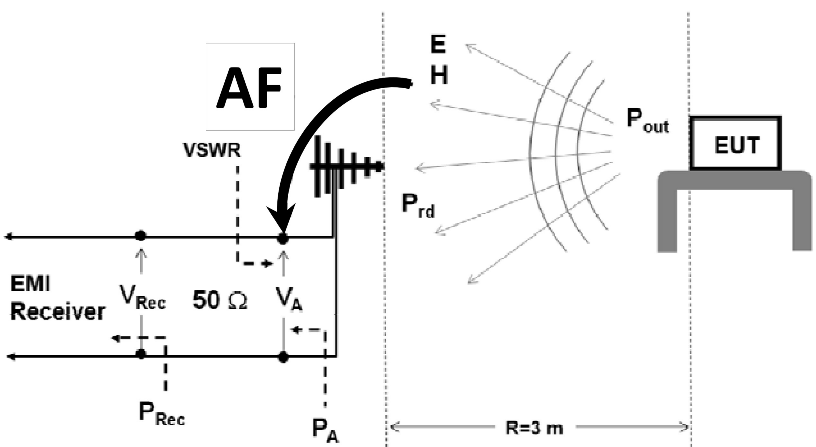
L. Sevgi / Hilton-Ankara Apr 13, 2016

Accreditation



Calibration

Antenna calibration



- EMI receiver measures V_{Rec}, but displays E; how are these two related?

EMC Tests & Measurements

Why measurement ?

- For the process control
- For the process design
- For the process optimization
- To show the compatibility with the standards

What quantities to measure?

- Operating frequency
- Power
- Temperature
- Pressure, velocity
- Material properties (σ, ε, μ)
- Current / Voltage
- Electric and magnetic fields

EMC Tests & Measurements

A Feature of EMC Engineers:

- EMC engineers never agree

UNLESS THEY ARE DRUNK!

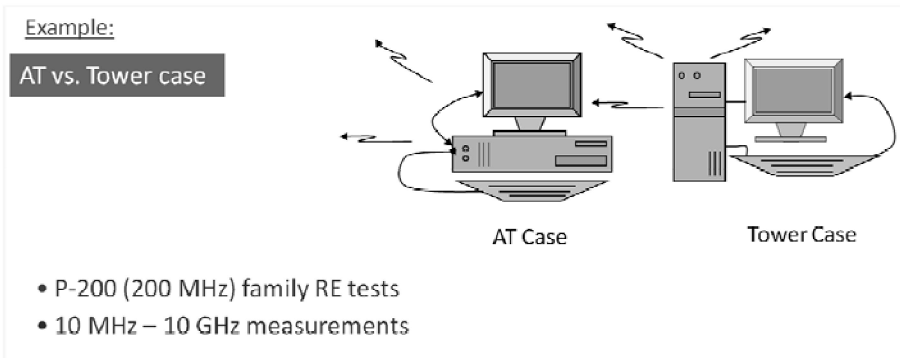
A Tip to EMC Engineers:

- If you want to be sure

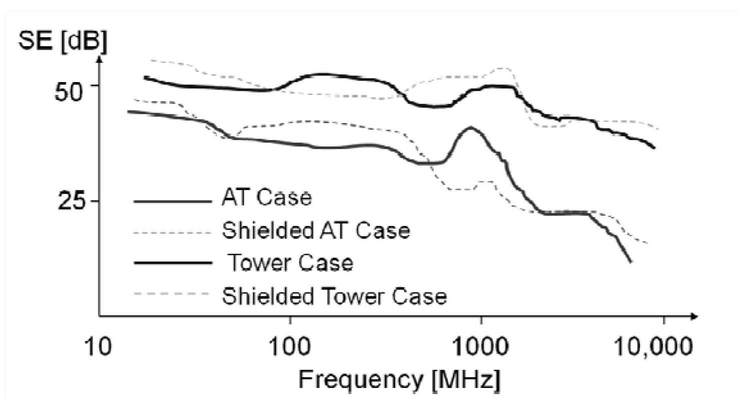
NEVER MEASURE TWICE!

A typical EMC measurement

- Many electronic devices have to live side by side in a close proximity.
- Their operating frequencies are also in the same bands.
- Their mutual interference have become crucial!

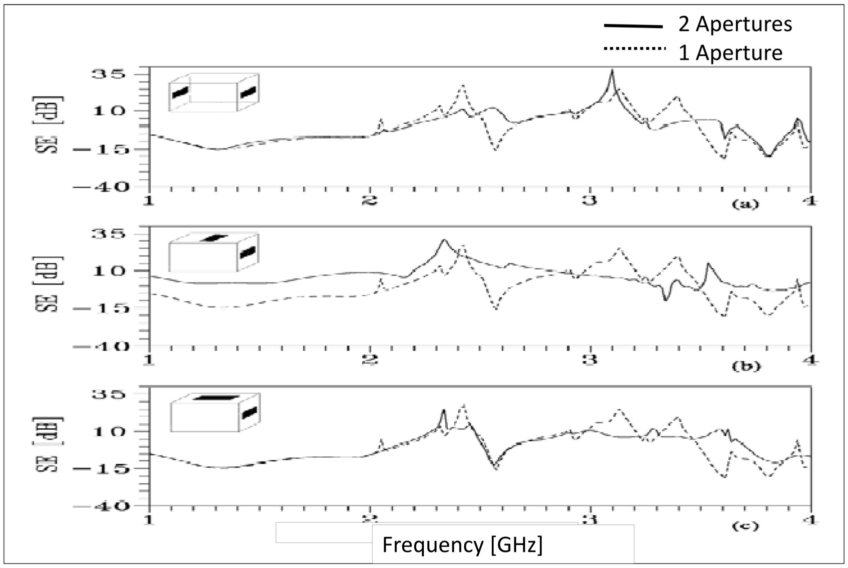


A typical EMC measurement



- 200 MHz clock spped creates problems in and above UHF band.
- SE performance is better in Tower cases.
- Today, we have computers in the market with 5-10 GHz clock frequencies.
- The first 10 hormonics reach to 100 GHz.

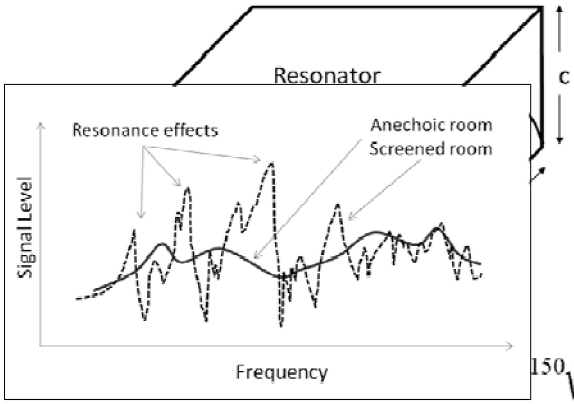
A typical EMC simulation



EMC Tests & Measurement Environments

EMC Tests & Measurements

Radiated Emission (RE)



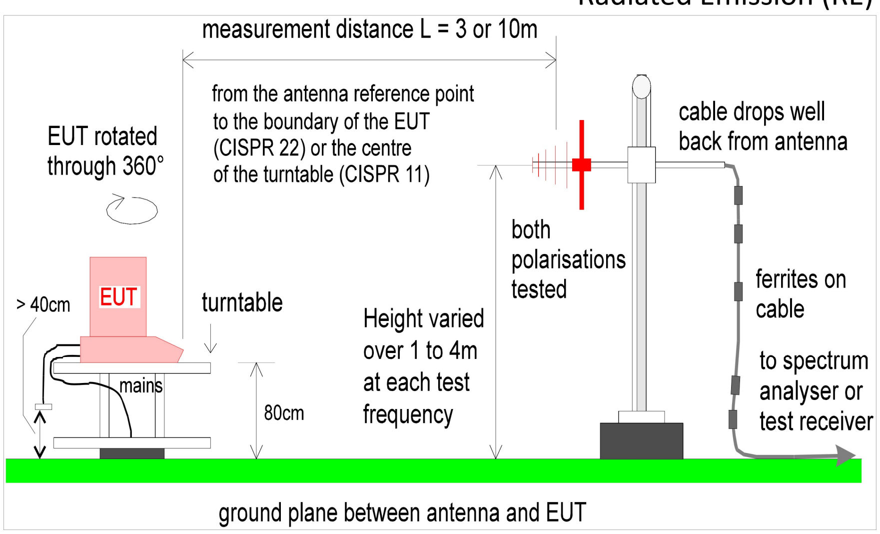
Dimen [m] a – b	Cut-off Freq [MHz]
15 - 30	11.2
15 - 20	12.5
10 - 20	16.7
10 – 10	21.2
5 - 10	33.5
5 - 5	42.4

$$150\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2+\left(\frac{l}{c}\right)^2}$$

Cut-off freqs → $TE_{110} = 150\sqrt{\left(\frac{1}{a}\right)^2+\left(\frac{1}{b}\right)^2}$ MHz

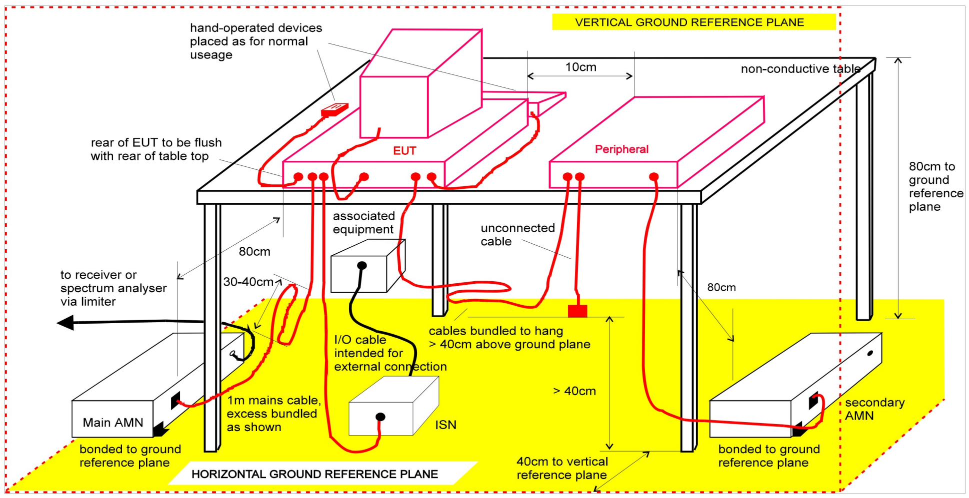
EMC Tests & Measurements

Radiated Emission (RE)



EMC Tests & Measurements

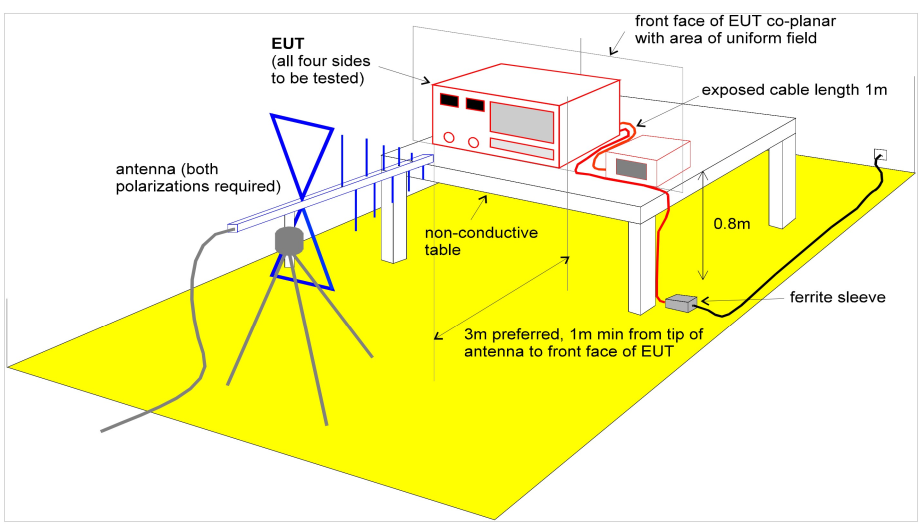
CE: Conducted Emission



L. Sevgi / Hilton-Ankara Apr 13, 2016

EMC Tests & Measurements

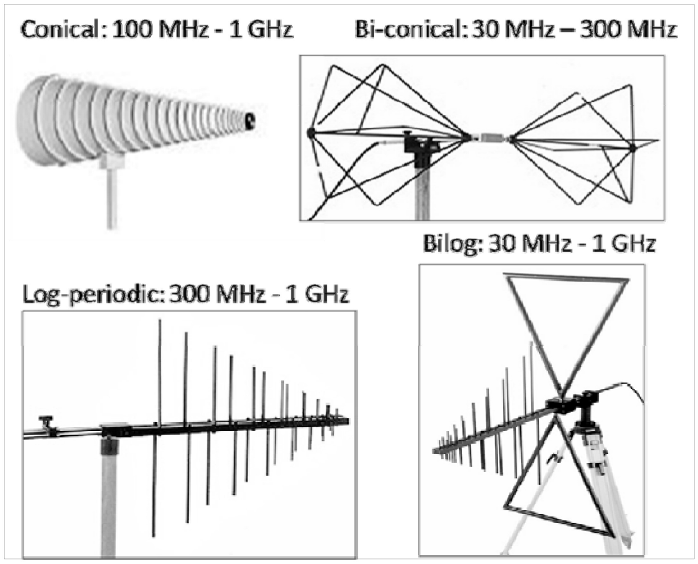
RI: Radiated Immunity



L. Sevgi / Hilton-Ankara Apr 13, 2016

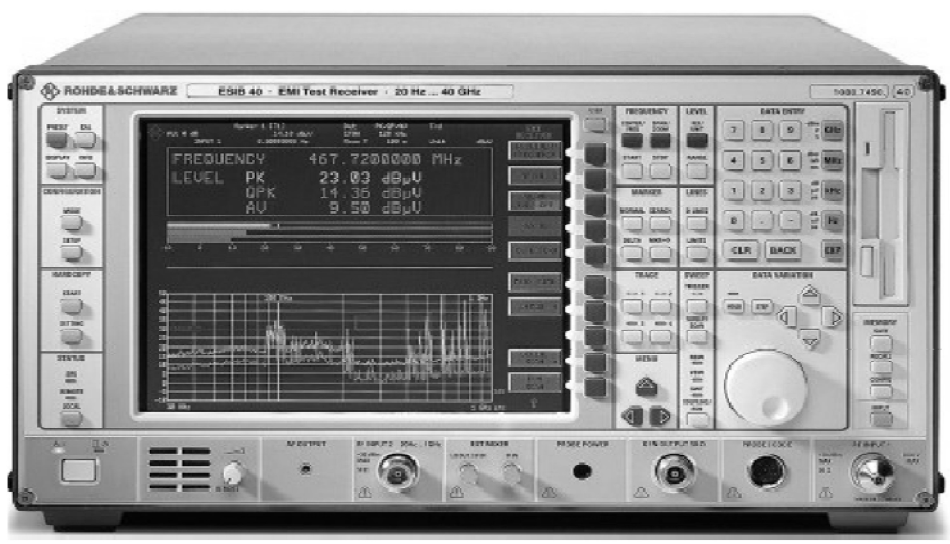
EMC Tests & Measurements

EMC antennas



EMC Tests & Measurements

EMI Alıcısı



EMC Tests & Measurements

EMI Receiver

Specifications

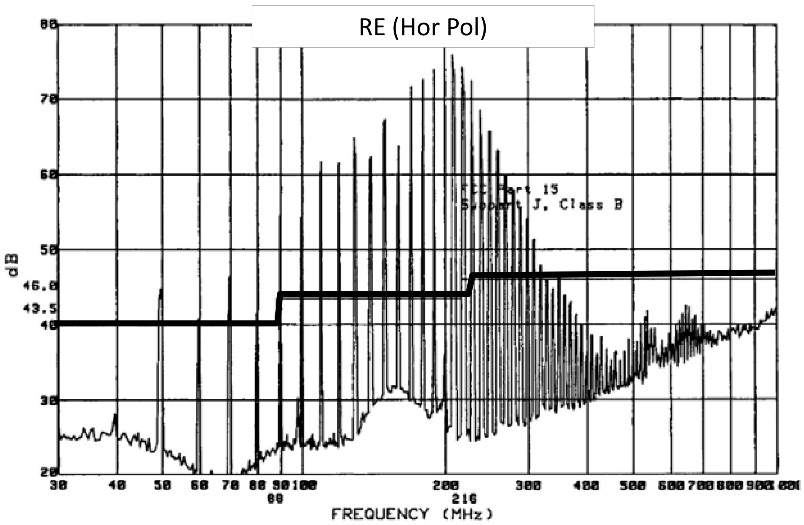
Frequency	
Range	100 kHz to 3 GHz (Option 5
	100 kHz to 6 GHz (Option 5
Frequency readout accuracy	± (frequency indication x f
	1% x span + 10% x RBW +
Internal reference accuracy	≤ ± 5 ppm/year (within 2 y
Aging rate	≤ ± 2 ppm/year
Temperature stability	≤ ± 1 ppm
Resolution bandwidth (RBW)	10 Hz to 200 kHz in 10% st
Selectivity (60 dB/3 dB bandwidth ratio)	Digital, approximately Gau
Span > 0; RBW ≤ 200 kHz	< 8.4:1 (nominal)
Span > 0; RBW ≥ 250 kHz	< 4.5:1 (nominal)
Zero span: RBW ≤ 10 kHz	< 6.5:1 (nominal)
Zero span: RBW ≤ 200 kHz	< 3:1 (nominal)
Zero span	3 kHz to 5 MHz in 1, 3, 5 sequence, 250 kHz and 1.25 MHz
Accuracy	
(RBW ≤ 200 kHz)	< 2% zero span; < 7% span > 0 (nominal)
(RBW = 250 kHz, 300 kHz, 1 MHz, 3 MHz)	< 4% zero span; < 4% span > 0 (nominal)
Video bandwidth (VBW)	1 Hz to 8 MHz and 50 MHz (wide open)
	1 Hz to 10 Hz in 1 Hz steps
	10 Hz to 3 MHz in 10% steps 4, 5, 6, 8, 30 MHz

Ho do you know these definitions?

- Readout Accuracy
- Precision
- Resolution Bandwidth
- Selectivity
- Temperature Stability
- Phase noise
- Harmonic parasitics, etc.

EMC Tests & Measurements

EMC Tests & Measurements



ESD levels

- Human
  ----
  up to 15-17 kV static charge
  up to 100-150 pF capacitor
  up to 12 mJ energy storage
- Vehicle
  ----
  up to400 kV static charge
  up to 10-15 nF capacitor
  up to 2 kJ energy storage

2 mJ is the value in the standards
350 mJ is the limit value
10 J life threat

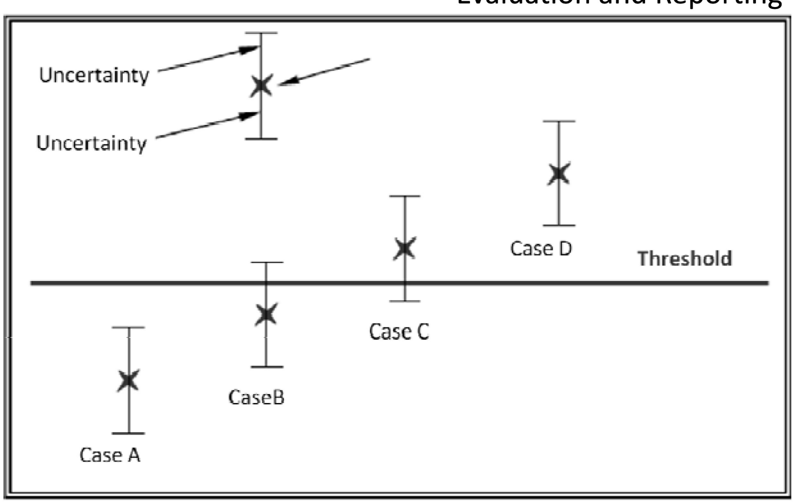
ESD Immunity Tests

L. Sevgi / Hilton-Ankara

Apr 13, 2016

EMC Tests & Measurements

Evaluation and Reporting



All the procedure should be reliable!

L. Sevgi / Hilton-Ankara

Apr 13, 2016

EME Problems & Classical Approaches

Electromagnetic Theory

Maxwell's Eq. in Diff. Form	Maxwell's Eq. in Integral Form
$\nabla \cdot \vec{D} = \rho$	$\oint_S \vec{D} d\vec{s} = \int_V \rho dv$
$\nabla \cdot \vec{B} = 0$	$\oint_S \vec{B} d\vec{s} = 0$
$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	$\oint_C \vec{E} d\vec{l} = -\frac{\partial}{\partial t} \int_S \vec{B} d\vec{s}$
$\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}$	$\oint_C \vec{H} d\vec{l} = \frac{\partial}{\partial t} \int_S \vec{D} d\vec{s} + \int_S \vec{J} d\vec{s}$
$\vec{D} = \varepsilon \vec{E}, \vec{B} = \mu \vec{H}, \vec{J} = \sigma \vec{E}$	

EME Problems: Available models

High Frequency Asymptotics (Analytical Methods)

GO : **G**eometric **O**ptics (plane wave, reflection + refraction)
GTD : **G**eometric **T**heory of **D**iffraction (GO + diffraction)
PO : **P**hysical **O**ptics (surface currents, reflection + refraction)
PTD : **P**hysical **T**heory of **D**iffraction (PO + diffraction)

Numerical Techniques

FDTD : **F**inite **D**ifference **T**ime **D**omain
(direct discretization of Maxwell's Equation)
TLM: **T**ransmission **L**ine **M**atrix
(3-Dimensional transmission line matrix representation)
MoM : **M**ethod **o**f **M**oments
(requires derivation of Green's function)
PE M: **P**arabolic **E**quation **M**ethod
(one-way axial propagation simulation)
FEM: **F**inite **E**lement **M**ethod
(requires discretization in terms of patches)

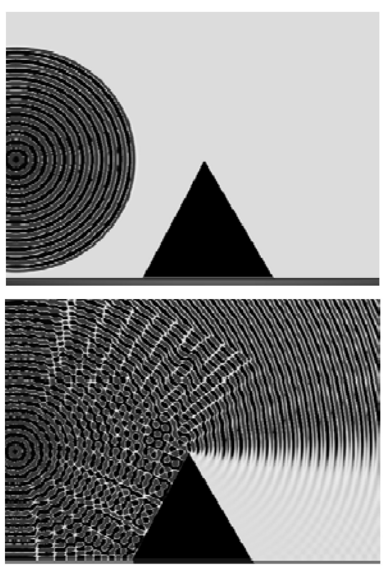
EM Wave Scattering

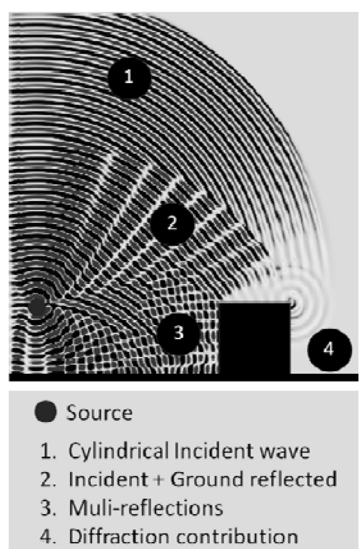
EM waves
interact with objects
and Scatter.

Wave Scattering includes
Reflection
Refraction
and Diffraction.

L. Sevgi / Hilton-Ankara Apr 13, 2016

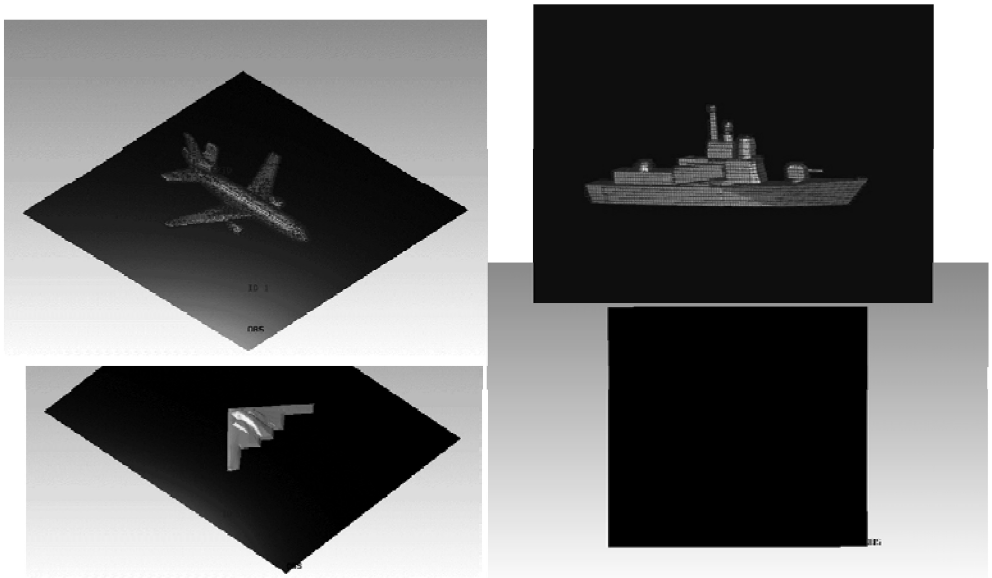
EM Wave Scattering





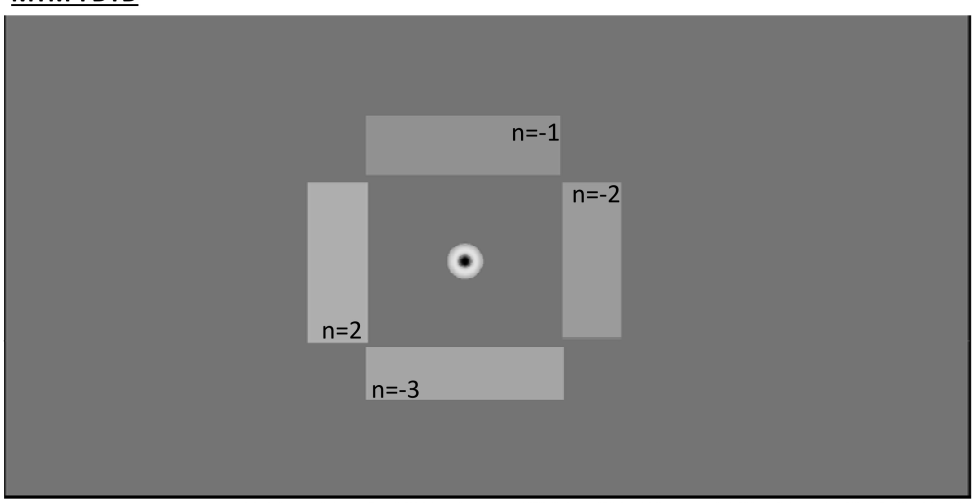
L. Sevgi / Hilton-Ankara Apr 13, 2016

EM Wave Scattering



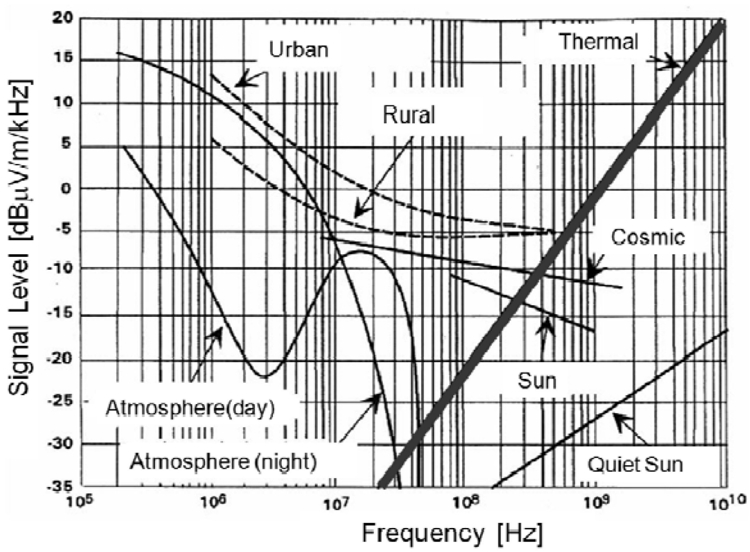
EM Wave Scattering

MTM-FDTD



M. Çakır, G. Çakır, L. Sevgi, "A Two-dimensional FDTD-based Virtual Metamaterial - Wave Interaction Visualization Tool," **IEEE Antennas and Propagation Magazine**, Vol. 50, No. 3, pp.166-175, Jun 2008

EMC & Noise



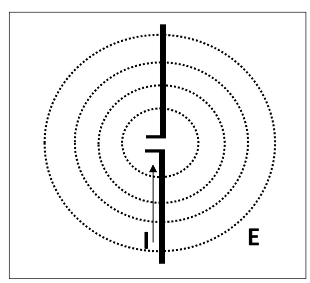
L. Sevgi / Hilton-Ankara

Apr 13, 2016

EMC Sources

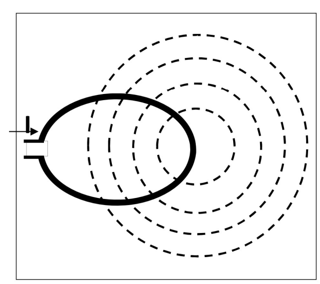
- Electric Dipole (Common mode radiation)
  Dipole antennas, OC transmission lines
  High Voltage/Low current
  High Impedance
  Electric Field is dominant in the near field

$$\left|E_{CM}\right|_{\max} = 0.63\times10^{-6}\,\frac{fI\ell}{r}$$



- Magnetic Dipole (Differential mode radiation)
  Currents flowing on a closed loop
  Low voltage/High current
  Low impedance
  Magnetic field is dominant in the near field

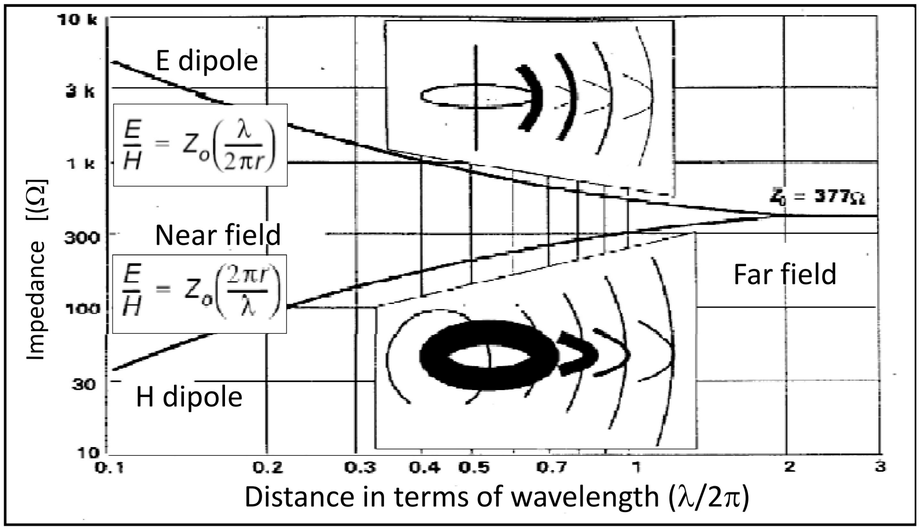
$$\left|E_{DM}\right|_{\max} = 1.32\times10^{-14}\,\frac{f^2IA}{r}$$



L. Sevgi / Hilton-Ankara

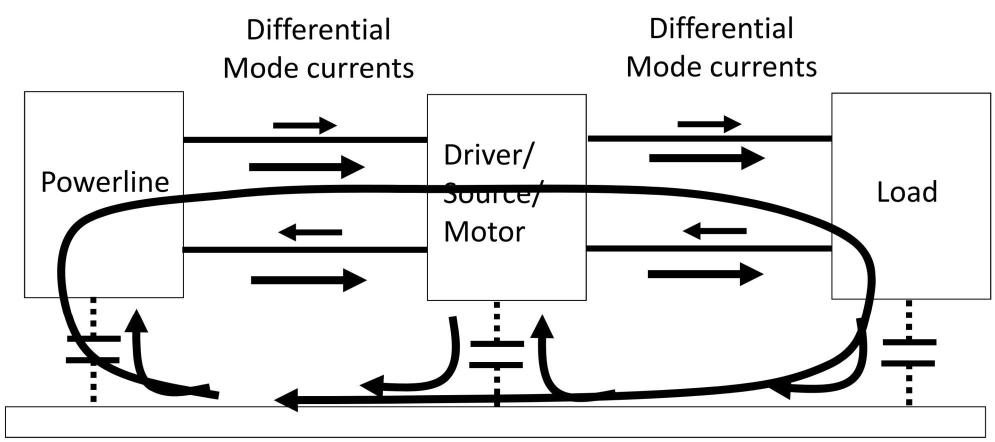
Apr 13, 2016

EMC Sources



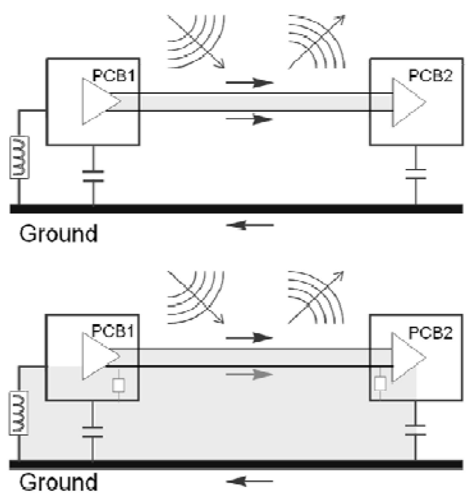
Differential and Common Mode Currents

Non-ideal grounding creates EMI problem:



Differential and Common Mode Currents

Differential and Common Mode Emissions



Differential mode

$$|E_{DM}|_{\max} = 1.32\times10^{-14}\,\frac{f^2 IA}{r}$$

Common mode

$$|E_{CM}|_{\max} = 0.63\times10^{-6}\,\frac{fI\ell}{r}$$

EM radiation mechanisms

- Magnetic dipole
  - Current: I = 1mA
  - Area: A = 50 mm x 5 mm
- Electrical dipole
  - Current: I = 5μA
  - Wire length: L = 100 mm

CISPR 22 LIMITS (Radiated) at 10m

Frequency	Class A	Class B
30 - 230 MHz	40 dB μV/m	30 dB μV/m
230 - 1000 MHz	47 dB μV/m	37 dB μV/m

Distance: R = 3m

Freq MHz	Mag Dipole dBμV/m	Elect. Dipole dBμV/m
30	6	16
50	15	20
100	27	26
200	39	32
300	46	36

Skin/Penetration Depth

- Electromagnetic waves can penetrate materials.
- Strenght of the wave varies inversely with the distance . This dependence is as: $\exp(-\mathrm{r}/\delta)$
- The attenuation depends on the frequency and conductivity of the material. The depth inside the material where the amplitude drops to 1/e is called **skin/peneration depth**:

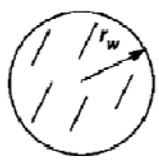
$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

L. Sevgi / Hilton-Ankara

Apr 13, 2016

Skin/Penetration Depth

Resistor effects

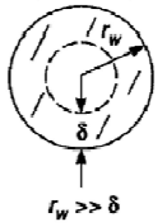


$$r_{\mathrm{dc}} = \frac{1}{\sigma\pi r_w^2} \quad \Omega/\mathrm{m}$$

$$\delta = \frac{1}{\sqrt{\pi f \mu_0 \sigma}} \quad \mathrm{m}$$

DC

AC

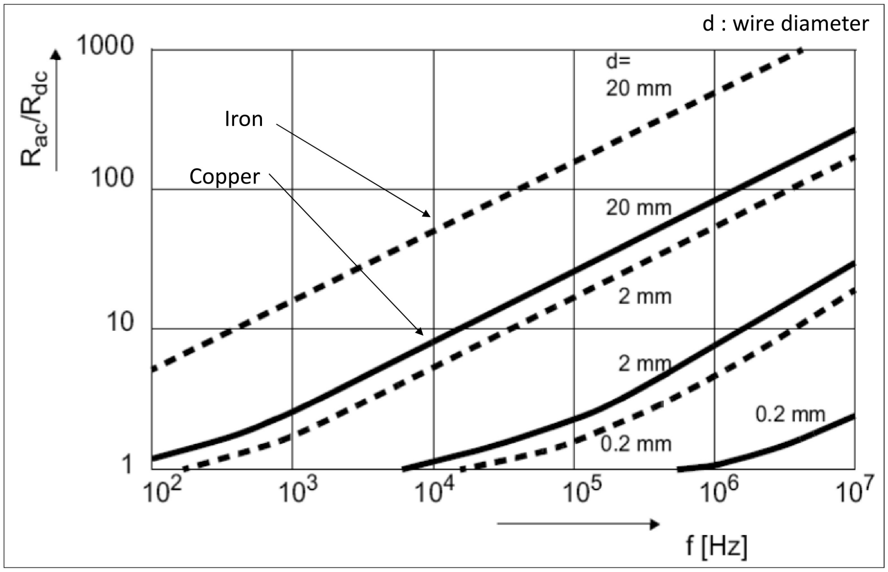


$$r_{\mathrm{hf}} = \frac{1}{\sigma(\pi r_w^2 - \pi(r_w - \delta)^2)} \cong \frac{1}{\sigma 2\pi r_w \delta} \quad \Omega/\mathrm{m}$$

L. Sevgi / Hilton-Ankara

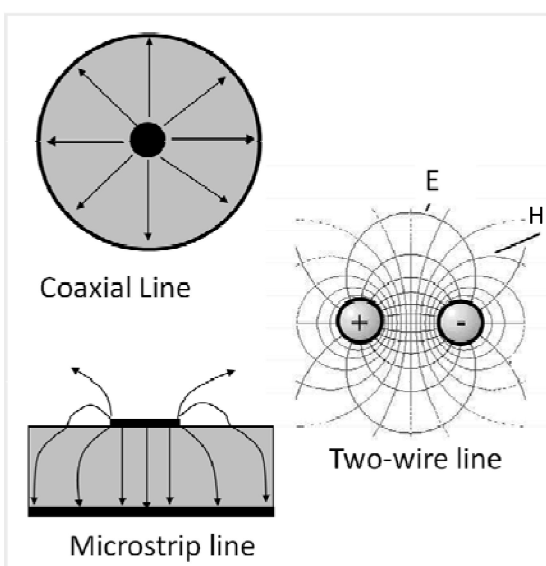
Apr 13, 2016

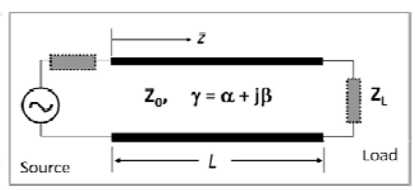
Skin/Penetration Depth



L. Sevgi / Hilton-Ankara Apr 13, 2016

Transmission Lines





$$\frac{d^2}{dz^2} V(z) = \gamma^2 V(z)$$

$$\frac{d^2}{dz^2} I(z) = \gamma^2 I(z)$$

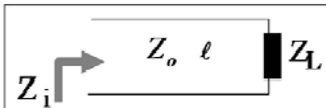
$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta$$

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad [\Omega]$$

L. Sevgi / Hilton-Ankara Apr 13, 2016

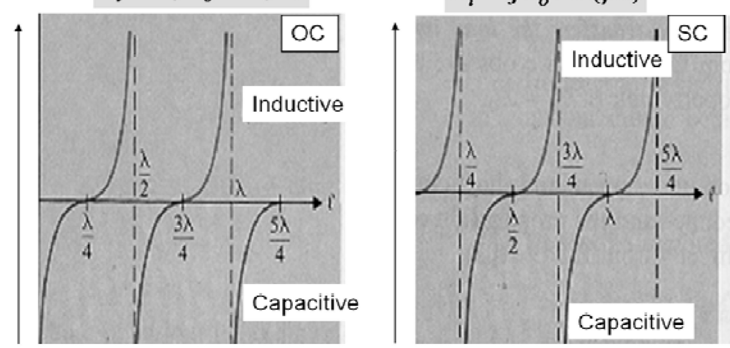
Transmission Lines

- Any L or C “effect” can be realized with a piece of TL.



$$Z_i = Z_o \frac{Z_L + jZ_o \tan(\beta\ell)}{Z_o + jZ_L \tan(\beta\ell)} \quad [\Omega]$$

Im {Z} $Z_i = -jZ_o \cot(\beta\ell)$ $Z_i = jZ_o \tan(\beta\ell)$



EMC Problems

When you are facing an EMC problem consider:

➔ Frequency

➔ Signal Strength

➔ Time / Duration

➔ Discontinuities / Impedance

➔ Geometry / Boundary Conditions.

EMC Problems

Take into account:

➔ Time - Frequency

➔ Frequency - Geometry

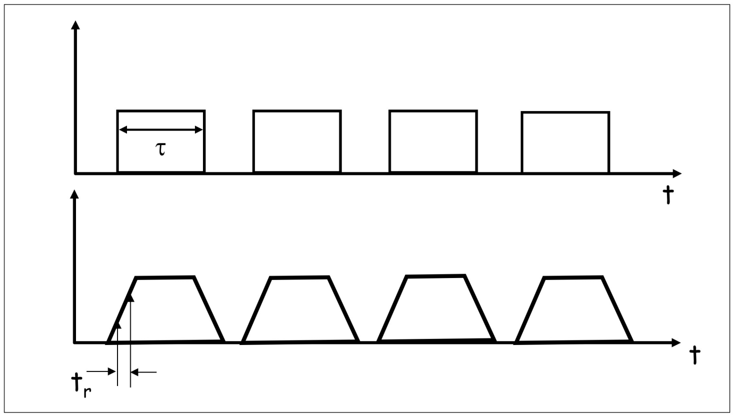
➔ Frequency - Impedance

relations.

Time – Frequency Relations

- Electromagnetic interference (EMI) maybe continuous or transient.
- It is much better and easier to deal with EMI problems in the frequency domain.
- Discrete signals have infinite number of harmonics.
- Fourier transform is used in signals and systems. It is a mathematical definition.
- Discrete Fourier Transform (DFT) is used in practice. Remember; it is numerical, not mathematical!

Time – Frequency Relations



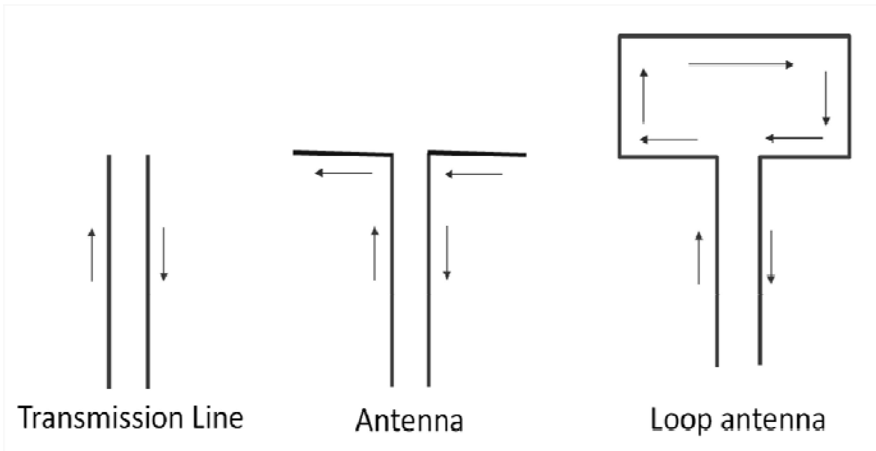
- EM emission is related to the rise time and pulse repetition frequency; immunity is related to the rise time.
- To increase clock frequency three (3) times increases the emissions 10 dB!

Frequency – Geometry Relations

- Equal and opposite currents decrease EM emission.
- The Geometry, i.e., dimensions (length or area) are two important keywords.
- EM emissions change with currents, frequency, and dimensions.
- A typical example for the loop antenna is the printed circuit boards (PCB).
- Cables and connectors are examples for dipole antennas.
- Slots also act as dipole antennas.
- Apertures and holes act as slot antennas (dominant at $\lambda/2$; still effective at $\lambda/20$).
- Always, reduce PCB areas and cable lengths.

Frequency – Geometry Relations

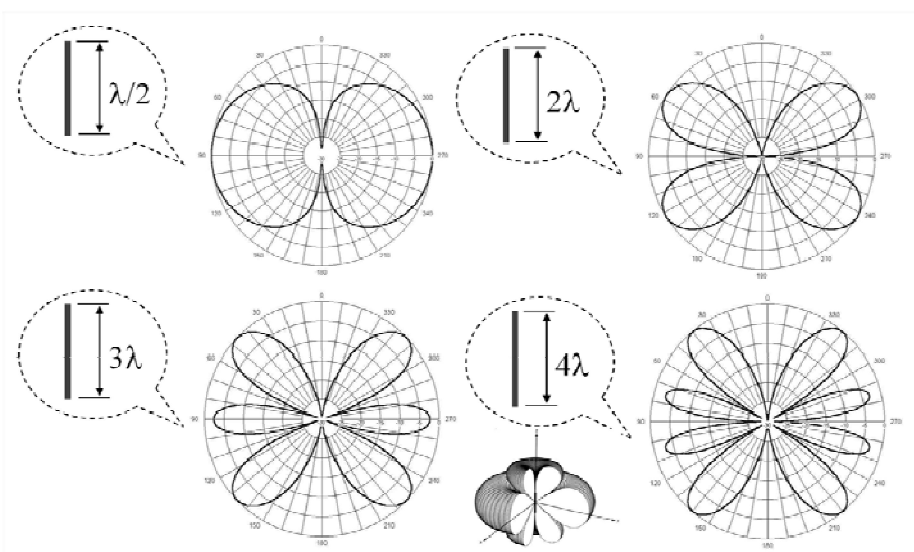
- Transmission Lines act as antennas; antennas act as TLs.



L. Sevgi / Hilton-Ankara

Apr 13, 2016

Frequency – Geometry Relations



L. Sevgi / Hilton-Ankara

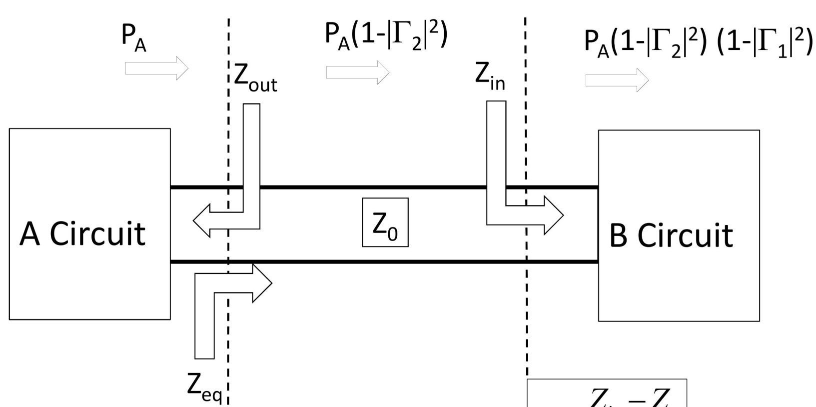
Apr 13, 2016

Frequency – Impedance Relations

- Impedance is an obstacle for the desired function/operation.
- Bolds act as inductances at high frequencies and increase the impedance, block the current.
- Bonding and leakage capacitors form alternative current paths.
- Impedance vs. Frequency of electronic elements are highly different than their theoretical models.

Frequency – Impedance Relations

Impedance Mismatch



$$\Gamma_2 = \frac{Z_{out} - Z_{Eq}}{Z_{out} + Z_{Eq}}$$

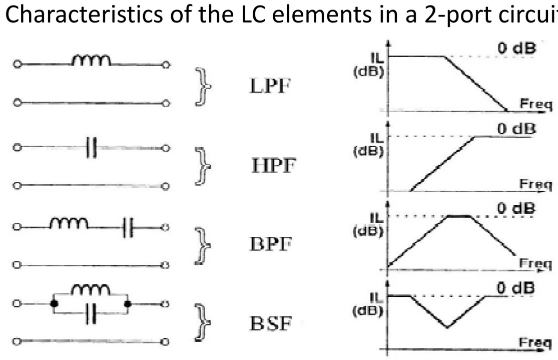
$$\Gamma_1 = \frac{Z_{in} - Z_o}{Z_{in} + Z_o}$$

EMC and Protection

- Separate systems, if possible:
  - Increase the distance
  - Use a shield in between
- Use a filter to suppress undesired frequencies:
  - LC/TL/Microstripline Filters
  - Ferrite Filters
- Match the impedances between systems:
  - Watch out the discontinuities
  - Beware of the skin/penetration depth
- Modify the grounding:
  - Beware of the common mode currents
  - Choose better grounding conductors.

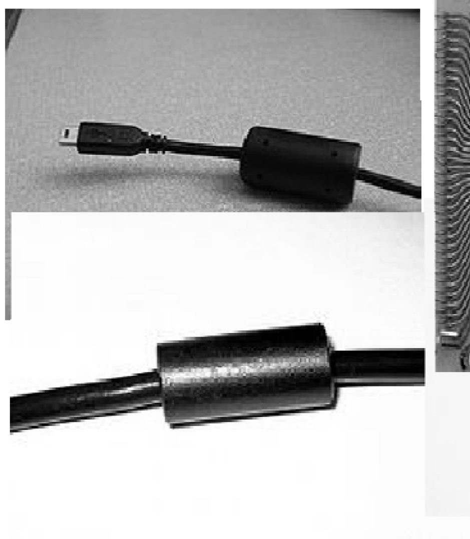
LC Filters

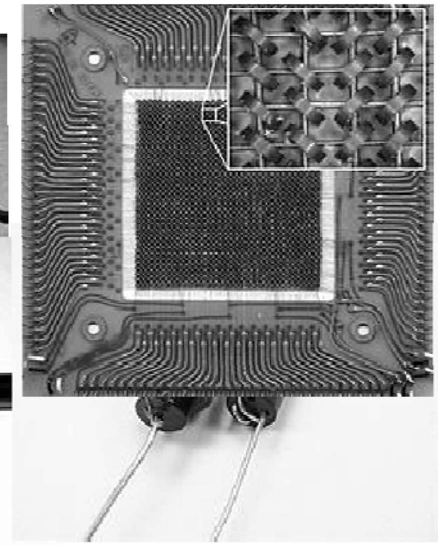
Characteristics of the LC elements in a 2-port circuit



- A series inductor(and/or a parallel capacitor) in a 2-port circuit acts as a LPF.
- A series capacitor(and/or a parallel inductor) in a 2-port circuit acts as a HPF.
- A serial resonance circuit(and/or a parallel resonance circuit) inserted serially in a 2-port circuit acts as a BPF.
- A parallel resonance circuit(and/or a serial resonance circuit inserted in parallel in a 2-port circuit acts as a BSF.

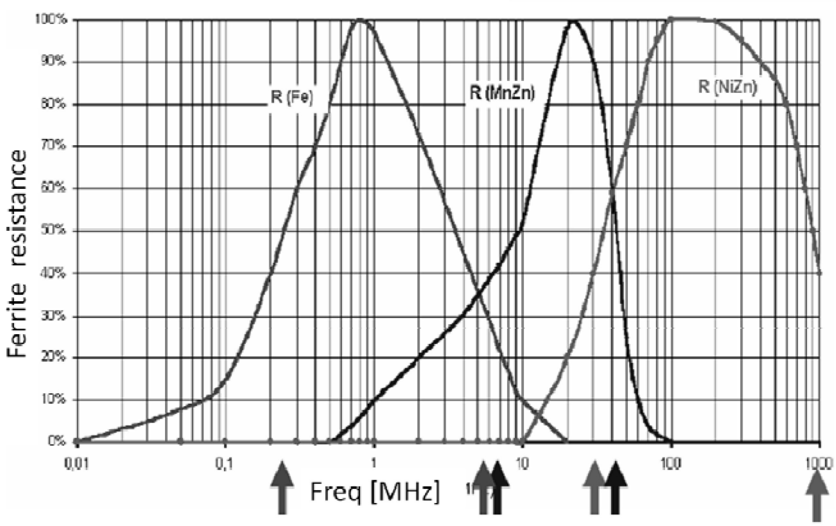
Ferrite Filters





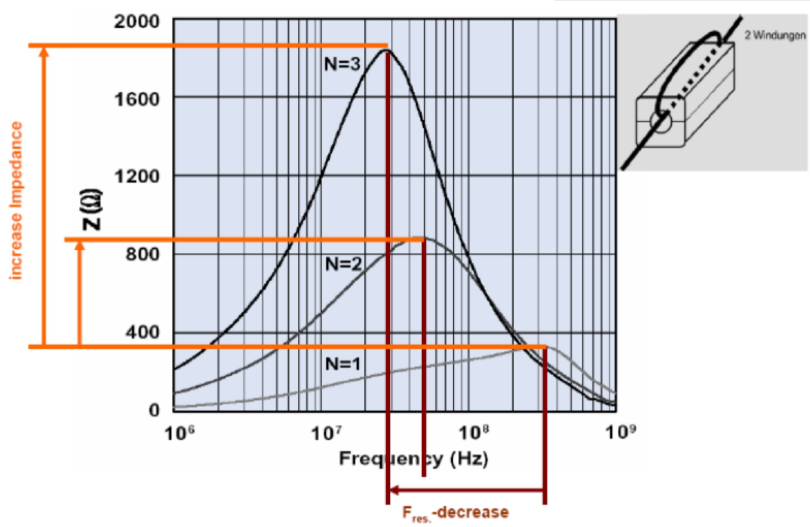
Ferrite Filters

Impedance vs. frequency



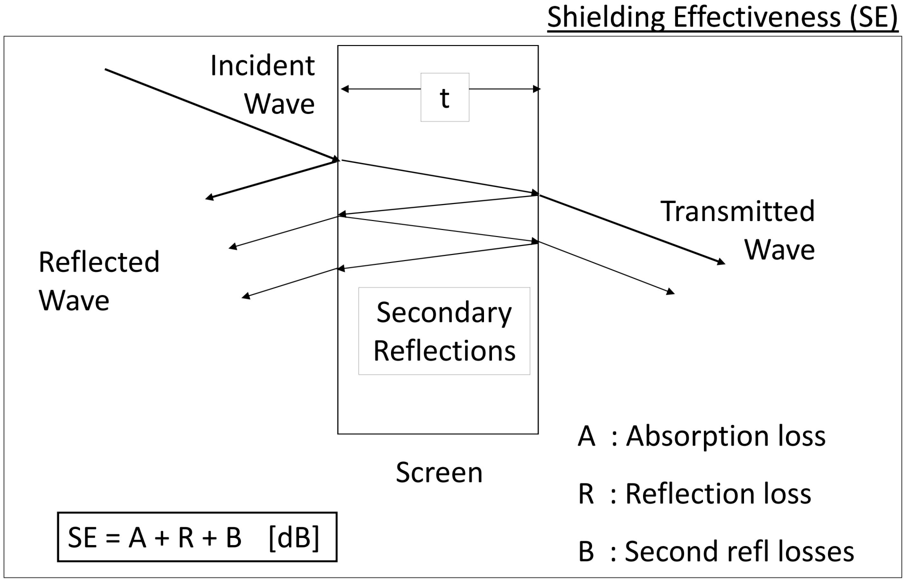
Ferrite Filters

Impedance vs. wind



EMC and Shielding

Shielding Effectiveness (SE)



EMC and Shielding

Shielding Effectiveness (SE)

worst case estimate: use magnetic or far field equations

	Far field	Near field	
	plane wave $Z = 377\ \Omega$	Electric predominant $Z > 377\ \Omega$	Magnetic predominant $Z < 377\ \Omega$
Absorption S_A=	$131\, d\sqrt{f\sigma_r\mu_r}$	$131\, d\sqrt{f\sigma_r\mu_r}$	$131\, d\sqrt{f\sigma_r\mu_r}$
Reflection S_R=	$168 + 10\log\left(\frac{\sigma_r}{f\mu_r}\right)$	$322 + 10\log\frac{\sigma_r}{\mu_r f^3 r^2}$	$14.6 + 10\log\frac{fr^2\sigma_r}{\mu_r}$
Correction S_{MR}=	0	0	0 if $S_A \geq 10$ dB otherwise: $30 + 10\log d^2 f\sigma_r\mu_r$
Total SE =	$SE = S_A + S_R$	$SE = S_A + S_R$	$SE = S_A + S_R + S_{MR}$

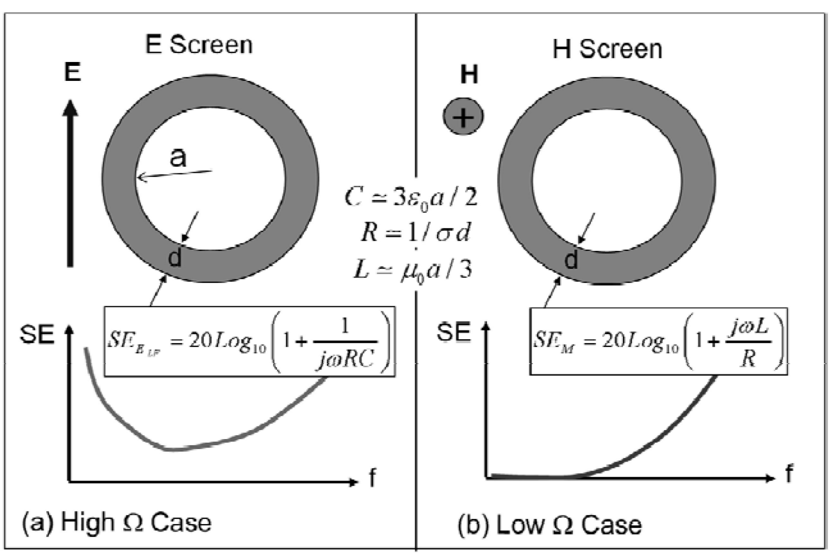
E-field: Academic case

f [Hz]
r [m]
d [m]

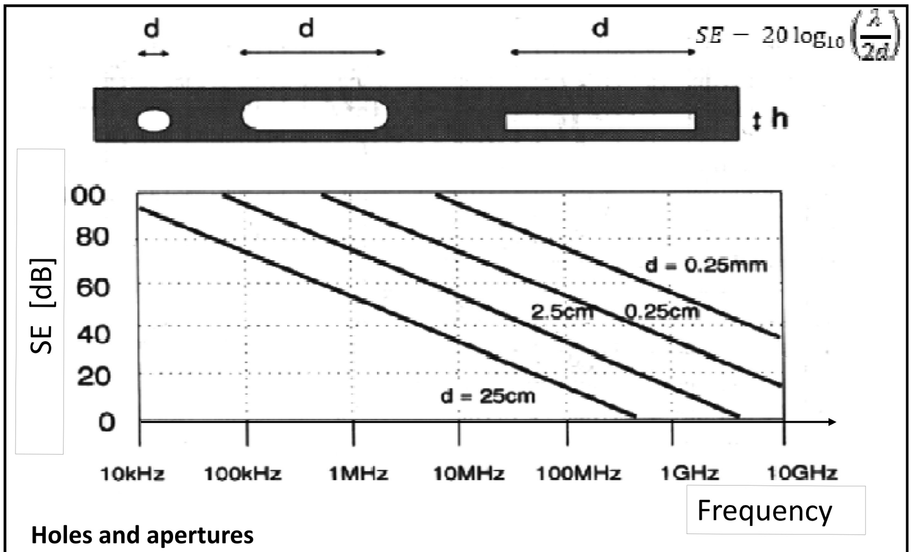
Screening ***E***ffectiveness

Screening by metal enclosures

EMC and Shielding



EMC and Shielding



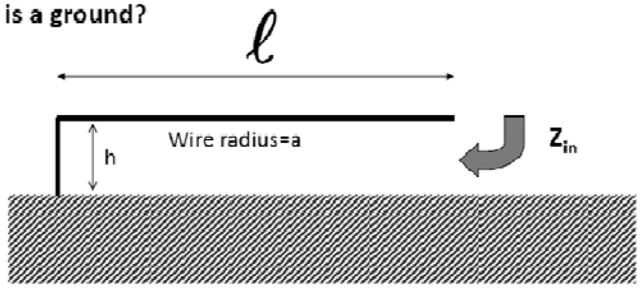
Holes and apertures

EMC and Grounding

- The classical definition of a ground is "an equipotential point or plane which serves as a reference for a circuit or system".
- Unfortunately this definition is meaningless in the presence of ground current flow. Even where signal currents are negligible, induced ground currents due to environmental magnetic or electric fields will cause shifts in ground potential.
- An alternative definition for a ground is "a low impedance path by which current can return to its source".
- This emphasizes current flow and the consequent need for low impedance, and is more appropriate when high frequencies are involved.
- It is important to remember that two physically separate "ground" points are not at the same potential unless no current is flowing between them.

EMC and Grounding

What is a ground?



Low-frequencies: $Z_{in} \approx R_{dc}$

Medium frequencies: $Z_{in} \approx j\omega L$

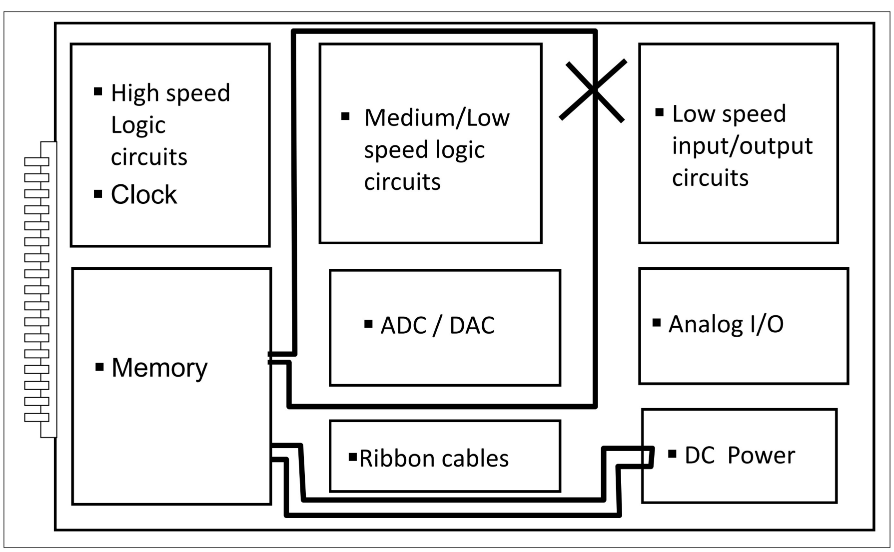
High frequencies: $Z_{in} = jZ_0 \tan(2\pi \ell / \lambda)$

$$if\ \ell = \lambda / 4 \xrightarrow{then} Z_{in} \to \infty \quad !!!$$

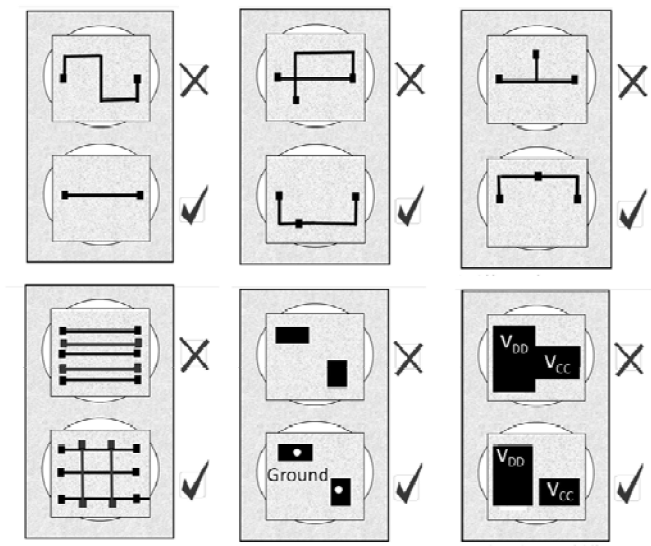
$$Z_0 = 60\sqrt{\frac{\mu_r}{\varepsilon_r}} \ln(2h/a)$$

C. Christopoulos

EMC and PCB Design



EMC and PCB Design



Conclusion

- EMC engineering is a multidisciplinary activity and involves physics, electronics, mechanics, chemistry and medicine. It has design, tests, production, quality, marketing, and legal implications.
- A conventional electromagnetic engineer is concerned with a range of product specific issues, whereas EMC engineers are concerned with all possible external electromagnetic influences on the environment.
- Moreover, issues related to design, prototying, tests & measurements, certification, importing & exporting, etc., have to be taken into account.

References

[1] L. Sevgi, Electromagnetic Modeling and Simulation, IEEE Press – John Wiley (EM Wave Series), Apr 2014

[2] L. Sevgi, A Practical Guide to EMC Engineering, ARTECH House, Norwood, MA, Mar 2017

[3] L. Sevgi, "EMC and BEM Engineering Education: Physics based Modeling, Hands-on Training and Challenges," IEEE Antennas and Propagation Magazine, Vol. 45, No.2, pp.114-119, April 2003.

[4] L. Sevgi, "From Engineering Electromagnetics towards Electromagnetic Engineering," ELEKTRIK, Turkish Journal of Electrical Engineering and Computer Sciences, Vol. 16, No.1, pp.i-v, Jan 2008

[5] L. Sevgi, "Electromagnetic Compatibility Engineering Education: Problems, Challenges and Perspectives," (special issue) TJEECS, Turkish Journal of Electrical Engineering and Computer Sciences, Vol. 17, No.3, pp. 273-278, Dec 2009